

LOW SPEED TURBO EGR

5 CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of the filing of U.S. Provisional Patent Application Serial No. 60/404,975, entitled "Low speed turbo/EGR", filed on August 21, 2002, and the specification thereof is incorporated herein by reference.

10 BACKGROUND OF THE INVENTION

Field of the Invention (Technical Field):

The present invention relates to the field of internal combustion engine exhaust gas recirculation (EGR) for emissions improvement and increased operating efficiency, including increased fuel economy. More particularly, the invention provides a system and
15 method for a new type of intermediate pressure EGR loop that is enabled by a two stage compressor.

Description of Related Art:

EGR is a known method for reducing the NOX emissions in internal
20 combustion engines. For effective use, an EGR system must overcome the adverse pressure gradient created by a positive pressure gradient across the engine which is typical of modern high efficiency diesel engines in at least a portion of their operating range. Various approaches to implementing EGR have included pumping of a portion of the exhaust gas from the exhaust manifold to the intake manifold. Pumping has been
25 accomplished by introducing the exhaust gas into the compression inlet of a conventional turbocharger or supercharger present on the engine or, alternatively, providing a separate compressor receiving the exhaust gas and pressurizing it to a suitable pressure for insertion into the charge air downstream of the charge air boosting system on the engine. Some fuel consumption penalty is generally incurred by these systems.

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EGR also requires adequate mixing of recirculated exhaust gas with the incoming intake air charge to avoid performance degradation and to minimize mixing losses to avoid additional fuel consumption penalties. Further, positive control of the recirculated exhaust gas flow is required to assure proper proportions in the charge air mixture supplied to the engine intake manifold under varying operating conditions. Additionally, the components and features of an EGR system must be accommodated within the constraints of limited volume available for allocation in modern engine compartments.

Low pressure loop EGR typically takes exhaust gas from the exhaust manifold, downstream of particulate traps and other emission control devices, and injects the exhaust gas into the compressor. The resulting compressed gas, typically mixed with intake air, is delivered to the intake manifold of the engine. Low pressure loop EGR works well at low power or load settings, reducing the fuel economy penalty that a high pressure loop would incur at low loads, and allowing very high EGR rates to be achieved. However, at high power or load settings low pressure loop EGR incurs a very large fuel penalty due to the need for flow ranges outside the capabilities of turbine-driven compressors, a poor turbine-to-compressor flow match and excessive heat loads, as well as the increase in back pressure caused by the need to boost the EGR exhaust gas to a pressure greater than that of the intake manifold. Multiple single stage turbochargers are not preferred as a solution because of the added cost and space and reliability requirements necessary to achieve high compression ratios.

Similarly, high pressure loop EGR works best at moderate to high loads, minimizing the boost pressure required. However, at low loads, high pressure loop EGR systems suffer from a large reduction in fuel economy due to the negative pressure differential required to drive the required high EGR rates.

BRIEF SUMMARY OF THE INVENTION

The invention provides an intermediate pressure EGR system for an internal combustion engine, preferably a diesel engine, comprising a turbocharger including a

compressor having more than one stage, and preferably having two stages. Unlike traditional high or low pressure EGR systems, the present invention provides increased fuel economy under all load conditions. A control valve determines the proportion of exhaust gas to be recirculated, and helps to control the pressure of the exhaust gas. The remainder of the exhaust gas turns the turbine of the turbocharger and is discharged to the environment. The turbine is optionally a variable geometry turbine. The discharge gas optionally flows through one or more emissions control devices. The exhaust turbine pressure ratio maintains the EGR flow at the turbine inlet pressure, which is less than the pressure at the intake manifold of the engine. The recirculated exhaust gas preferably flows through a diesel particulate filter and is optionally cooled by an EGR cooler. The diesel particulate filter is optionally a miniature diesel particulate filter. The first stage of the compressor boosts the intake air to an intermediate pressure. The compressed intake air is optionally cooled by an air/air charge cooler. The intake air and exhaust gas to be recirculated are then mixed, preferably by an EGR mixer. The mixture is optionally cooled by an Air/EGR cooler, then injected into the second stage of the two stage compressor, which boosts the mixture pressure to a level sufficient to satisfy the mass flow demand of the engine. The mixture is cooled with an air/air charge cooler before entering the intake manifold.

The invention also provides an EGR system wherein a turbocharger maintains a pressure of exhaust gas at an intermediate pressure lower than the pressure at the intake manifold, thereby improving the fuel economy over other low or high pressure EGR systems. The exhaust gas pressure is greater than the pressure of intake air, which has been compressed by the first stage of a two stage compressor. The exhaust gas to be recirculated is mixed with the intake air and the mixture is compressed by the second stage of the compressor to a pressure required to provide the desired mass flow to the engine.

The invention further provides a method of providing exhaust gas recirculation to an internal combustion engine, comprising the steps of maintaining the exhaust gas at an intermediate pressure less than the pressure at the intake manifold, optionally filtering the exhaust gas, optionally cooling the exhaust gas, using the first stage of a multiple stage

compressor to increase the pressure of intake air to a pressure less than the intermediate pressure of the exhaust gas, mixing the exhaust gas and intake air, and boosting the pressure of the mixture to a pressure sufficient to meet the mass flow demand of the engine. Maintaining the pressure of the exhaust gas is preferably accomplished by using
5 back pressure from a turbocharger turbine. The pressure of the mixture is preferably boosted by a secondary stage of the compressor.

Other objects, advantages and novel features, and further scope of applicability of the present invention will be set forth in part in the detailed description to follow, taken in
10 conjunction with the accompanying drawings, and in part will become apparent to those skilled in the art upon examination of the following, or may be learned by practice of the invention. The objects and advantages of the invention may be realized and attained by means of the instrumentalities and combinations particularly pointed out in the appended claims.

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BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated into and form a part of the specification, illustrate one or more embodiments of the present invention and, together with the description, serve to explain the principles of the invention. The drawings are
20 only for the purpose of illustrating one or more preferred embodiments of the invention and are not to be construed as limiting the invention. In the drawings:

FIG. 1 is a schematic diagram of an engine and EGR system employing the components of the present invention; and

FIG. 2 is a schematic diagram of an alternative embodiment of the present
25 invention.

DETAILED DESCRIPTION OF THE INVENTION

Referring to the drawings, FIG. 1 shows an internal combustion engine system 10 including the intermediate pressure loop EGR system of this invention. Internal
30 combustion engine 14 has at least one cylinder in communication with exhaust manifold 18 and intake manifold 16. Exhaust manifold 18 is connected to exhaust line 20 which in turn is connected to control valve 22, which controls the relative amount of exhaust gas

entering either the intermediate pressure EGR loop line **50** or the exhaust turbine line **24**. Control valve **22** also partially controls the pressure within the EGR line. Exhaust gas not diverted to intermediate pressure EGR loop line **50** by control valve **22** is directed by means of exhaust turbine inlet line **24** to exhaust turbine **32**. Exhaust gas entering
5 exhaust turbine **32** produces rotational energy, thereby driving two-stage compressor **80** which comprises first stage **34** and second stage **36**. Exhaust gas exits turbine **32** by means of exhaust line **38** and is discharged into the atmosphere, optionally through various emission control devices (not pictured), including but not limited to a catalytic converter, a diesel oxidation catalyst (DOC), a lean NOX trap (LNT), and/or a diesel
10 particulate filter (DPF).

Turbocharger **100**, which comprises two stage compressor **80**, connecting shaft **30**, and exhaust turbine **32**, is optionally a variable geometry turbocharger. In one embodiment of a variable geometry turbocharger the vanes of exhaust turbine **32** are
15 actuated by an actuator, such as a hydraulic actuator, so that the efficiency or operational flow range of exhaust turbine **32** can be varied during operation, thereby providing for optimal system efficiency and mass flow control. A variable geometry turbocharger provides for increased system efficiencies not readily obtainable with standard turbochargers. A variable geometry turbocharger is disclosed in commonly owned United
20 States Patent No. 6,269,642, issued August 7, 2001, and incorporated herein by reference. However, it is to be understood that the invention is not limited to the variable geometry turbocharger of Patent No. 6,269,642, and that other variable geometry turbochargers may be employed, and further that turbochargers not providing for variable geometry may be employed.

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Exhaust gas in intermediate pressure EGR loop line **50** is maintained by exhaust turbine **32** at an intermediate pressure less than the pressure at the intake manifold **16** of engine **14**. Exhaust gas diverted to intermediate pressure EGR loop line **50** passes through DPF **52**, which DPF **52** is optionally miniature in size, and is cooled by EGR
30 cooler **54**. Intake air enters first stage **34** at air intake **40**, is compressed by first stage **34** to an intermediate pressure less than the pressure at the intake manifold, exits through air line **42**, and is cooled by air/air charge cooler **44**. The exhaust gas pressure in

intermediate pressure EGR loop line **50** is sufficiently higher than the discharge pressure of the first stage **34** to eliminate the need for creating a negative pressure gradient to enable the EGR to flow in the correct direction. However, that exhaust gas pressure is less than the pressure at intake manifold **64**.

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The cooled intake air and exhaust gas are mixed together by EGR mixer **46** to form an Air/EGR mixture. The pressures within loop line **50** and air line **42** are each at an intermediate pressure lower than that at intake manifold **16**, with the pressures being matched by control valve **22**. Thus, the back pressure at the exhaust manifold **18** is lower than it would be if the exhaust gas had been restricted, raising it above the pressure at intake manifold **16**, thus thereby reducing the work required to be done by engine **14**. The lower back pressure and reduced work improve fuel economy greatly over known low or high pressure EGR systems.

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The Air/EGR mixture exit EGR mixer **46** by means of second stage inlet line **48** and enters second stage **36** of compressor **80**. Second stage **36** compresses the Air/EGR mixture to a pressure required by the engine to transit the desired mass flow. The Air/EGR mixture is cooled by air/air charge cooler **62** and proceeds through intake line **64** to enter intake manifold **16**.

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Commonly owned U.S. Patent No. 6,062,028, issued May 16, 2000, incorporated herein by reference, discloses a low speed, high compression ratio turbocharger with minimal packaging size comprising a two stage compressor. However, it is to be understood that the invention is not limited to the turbocharger of Patent No. 6,062,028, and that other two stage compressor turbochargers, or turbochargers with more than two stages, may be employed.

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FIG. 2 shows an internal combustion engine system **12** including an alternative embodiment of the low pressure loop EGR system of this invention. This embodiment is identical to the embodiment depicted in FIG. 1, except that exhaust gas exiting DPF **52** proceeds directly to high temperature EGR mixer **72** without first being cooled. Similarly, intake air compressed by first stage **34** of compressor **80** passes through air line **70**

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directly to high temperature EGR mixer **72** without first being cooled. After the compressed intake air and exhaust gas are mixed together by high temperature EGR mixer **72** to form an Air/EGR mixture, the mixture is then cooled by Air/EGR cooler **76** and proceeds along second stage inlet line **78** and enters second stage **36** of compressor **80** as described above.

Although the invention has been described in detail with particular reference to these preferred embodiments, other embodiments can achieve the same results. Variations and modifications of the present invention will be obvious to those skilled in the art and it is intended to cover in the appended claims all such modifications and equivalents. The entire disclosures of all references, applications, patents, and publications cited above are hereby incorporated by reference.